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ABSTRACT

During the period 1984-1986, over 30 teachers from the Yorkshire (England) region have worked in collaboration with the Children's Learning in Science Project (CLIS) developing and testing teaching schemes in the areas of energy, particle theory, and plant nutrition. The project is based upon the constructivist approach to teaching. The purpose of this booklet is to describe some of the teaching strategies that were derived and subsequently used in the project. It is intended to provide a description of some of the successes, problems, and outcomes of the project. The document contains sections on: (1) how children learn (including a description of constructivism); (2) a generalized teaching scheme (focusing on the stages in the constructivist teaching sequences); (3) demands on the pupil; (4) demands on the teacher; and (5) demands on resources. Included are a reference list and a list of related books for further reading. (TW)

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CHILDREN'S LEARNING IN SCIENCE PROJECT

IN THE CLASSROOM

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Teaching strategies for developing understanding in science

Richard Needham

in association with Peter Hill

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Children's Learning in Science Project

Teaching strategies for developing understanding in science

Richard Needham
in association with Peter Hill

June 1987

Centre for Studies in Science and Mathematics Education
The University
Leeds LS2 9JT

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"problem solving;

investigation;

practical work;

exposition;

discussion; and

consolidation and practice.

Such a range of teaching approaches seems to the Secretaries of State to be essential for the teaching of science .....
In particular, opportunities for pupils to contribute their own ideas to discussion are important .... Pupils should be given the opportunity to test their own ideas."

(Science 5-16: A Statement of Policy. D.E.S. 1985, p.17)

Acknowledgements

All members of the project team have had some part to play in the development of the work described here. Particular thanks are due to Sharon Crossley and Elisabeth Stephens for their patience and good humour through many redrafts.

We would also like to express our appreciation to the Headteachers, staff and students of all schools involved in the trialling of materials and to our local education authorities for their support of our involvement with this project; without their co-operation and help the work would not have been possible.

Finally, we would like to thank members of the Steering Committee and others for their helpful comments on the draft.

Preface

During the last three years over thirty science teachers from the Yorkshire region have worked in collaboration with the Children's Learning in Science Project, developing and trialling teaching schemes in the areas of energy, particle theory and plant nutrition.

It was felt that it would be useful to have a series of booklets written by teachers for teachers to present the theoretical rationale which underlies the schemes and also to provide practical advice for those taking up a constructivist approach to teaching.

A series of booklets has been planned and edited by P. Scott and R. Senior. The first two in the series are:

Booklet 1: A constructivist view of learning and teaching in science. P. Scott.

Booklet 2: Teaching strategies for developing understanding in science. R. Needham.

The booklets provide guidance on using the teaching schemes and should be read in conjunction with them. We hope that they will prove to be both interesting and helpful.

Introduction

The personal development experienced by the teachers involved with the Children's Learning in Science Project over the last two years has been accompanied by a range of feelings. Undoubtedly, there were feelings of fulfilment, increased perception and sensitivity to pupils and to teaching issues. There were also times when we experienced feelings of reservation, doubt and even anxiety when we attempted to use some of the materials we developed inside our own classrooms.

The purpose of this booklet is to describe some of our thinking, and some of the teaching strategies that we have derived and subsequently used. We hope that the recounting of our experiences during the trial phase of the project will stimulate some thought and discussion in staffrooms, and may allay some of the concerns that teachers may feel when implementing innovation.

We realise, of course, that the novelty of the CLIS materials lies in the underlying approach to learning, and not in the classroom activities themselves. The intention of this booklet is to document some of the successes, problems and outcomes that we have experienced.

1 How do children learn?

1.1 Constructivism

The Children's Learning in Science Project is based on a constructivist view of learning. Briefly, this view acknowledges that children construct their own knowledge through personal interaction with natural phenomena and through social interactions with adults and peers. As a result, children already hold beliefs about how the world operates before they come to formal science. We feel that one important role of the teacher is to produce a learning environment in which children can:

- recognise and reflect on their ideas,
- realise that other people may hold other conflicting, but equally valid ideas,
- evaluate the usefulness of these ideas alongside their teacher's 'scientific' theories.

When exposed to a range of learning activities, and given the opportunity to reflect, the pupils may then modify their ideas towards the intended learning outcome. Scientific 'knowledge' is taken to be a personal construction in the mind of the teacher, as well as in the mind of the pupil. For teachers to expect all of their pupils to reach the same understanding as themselves, or even each other, may not be a realistic goal. (For a more detailed account of this perspective, see Scott (1987).)

1.2 The status of what pupils learn

Most teachers would at least pay lip-service to the idea that they teach science to enable childen to make sense of the environment in which they live and to enable them to become confident citizens in a technological world.

In practice, however, we might ask whether the actual lesson activites do enable pupils to make better sense of things around them.

The following extract is from a lesson in a unit of work on particle theory. The pupils were asked to observe the behaviour of a soap film in a loop made by a piece of cotton being tied across a wire frame:

Teacher: What makes the soap film stick to the wire frame? ... Come on, which force is it? You've only got two words to choose from anyway. What? Adhesion. That's right. Because the wire and the soap film they're different materials so you get adhesion there - you get adhesion with the cotton - but the soap film itself is trying to shrink.

Later the pupils were asked to write a paragraph about everyday examples of cohesion and adhesion. Lynn wrote:

"TVs, tables, record players, pens, pencil cases, these are together because of cohesion. Glue, water, washing up liquid, drinks, these are adhesion."

When she was asked to explain what she had written a little further she said:

Lynn: Well, I didn't really get that much, but I knew that glue had adhesion, but I didn't really know if these were right or not (pointing to the rest of the paragraph).

Interviewer: I see. Why did you think that water, washing up liquid and drinks are adhesion? Can you explain why you think they are?

Lynn: Because they're not solid.

I: Mmm.

Lynn: And I thought that cohesion were things that were solid I thought that when particles go together, they make like a solid and when they're unlike they don't go together I thought they'd be like liquids.

Clearly Lynn's ideas about cohesion and adhesion were not what the teacher intended. As far as helping her understand particle ideas better they may even have been a hindrance.

This example illustrates the importance of considering the meaning children construct from experiences they are given. It is also worth reflecting on whether Lynn would ever choose to use the words 'cohesion' and 'adhesion' to help her understand her everyday experiences outside the school environment. With hindsight the teacher may have noticed that he was failing to engage his class in the discussion, but with an already crowded syllabus to follow, could he afford the time to respond to the situation?

1.3 Summary

1. For learning to be more effective teachers need to plan their lessons in a way which takes account of how children learn.
2. Teachers would benefit from finding out what their pupils already know, and should manage their lessons with pupil outcomes in mind.
3. Syllabus content may be overloaded with unnecessary concepts and vocabulary for some pupils.
4. Pressure caused by an apparent lack of time may result in ineffective teaching strategies being employed.

2 A generalised teaching scheme

2.1 Overview

"- a common problem in our schools is that we as educators give students symbols to learn but don't provide the necessary experiences to allow conceptualization to occur. As a result concepts are learned as names or words rather than as meaningful abstractions. To have meaning, the symbols for concepts must correspond to actual referents. If not, the words become hollow symbols, sounds without meaning.

Our brighter students learn to memorize symbols (words and groups of words such as sentences) and often resort to reciting the symbols as a substitute for learning a concept. The teacher, having forgotten the importance of the experiences that went into making the symbols meaningful, equates the words with the concept and assumes that concept learning has taken place. Only later, when students are unable to use the concept in discussions or to solve problems, do teachers realize what has happened."

P.D. Eggen, D.P. Kauchak, R.J. Harder,
Strategies for Teachers, 1979, p.43

The CLIS materials have been designed to encourage pupils to construct scientific ideas for themselves, by active involvement in their lessons. The learning process could be considered analogous to a building operation where the learner first has to investigate the foundations on which to build (their prior knowledge); building materials are then selected and then time is allowed for construction. Within the construction process, some attempts may be rejected and time must be provided for modification. A significant influence on the process will be social interaction, and opportunities for this have to be planned for in the teaching schemes. Implicit in these ideas is that learning is an active, not a passive process. Moreover, although the teacher has responsibility for providing organised learning activities, it is the learner who is responsible for the learning that occurs.

A further aspect of the teaching approaches adopted is to give learners an awareness of the learning process itself, to develop confidence and motivation for further learning to occur. Opportunities are provided within CLIS materials for learners to become more aware of changes in their ideas and to review their own learning (see Novak 1985).

All the schemes developed by the project follow a similar sequence through a topic of work. The five phases: orientation, elicitation, restructuring, application and review, are shown in figure 1. The rationale for this sequence has been outlined elsewhere (Scott 1987). Here we consider the more practical aspects of putting these strategies into practice in the classroom.

2.2 Stages in the constructivist teaching sequence

Orientation

Children are naturally curious about their surroundings. The purpose of the orientation stage is to focus their sense of enquiry on to a particular science issue. It is at this stage that the motivation to learn is aroused and so some of the CLIS schemes have allocated a whole double lesson of eighty minutes to this process. Other schemes have employed the strategy of posing an open-ended problem that is both realistic and meaningful to the pupils.

Elicitation

Children have ideas which they use to make sense of their world. Some of these ideas may be in keeping with those they will meet in school science. For example children usually acknowledge that:

Plants require water and light for growth to occur
Moving objects have energy

However, in some cases the ideas that children have differ from what they will be taught. For example, they may consider that:

Solids disappear when they dissolve
Energy gets used up
Heat rises.

PHASE	PURPOSE	METHODS
I ORIENTATION	Arouse interest and set the scene.	Practical activities, real problems to solve, teacher demonstrations, film clips, videos, newspaper cuttings.
II ELICITATION OF IDEAS	To enable pupils and teachers to become aware of prior ideas.	Practical activities or small group discussion followed by reporting back.
III RESTRUCTURING OF IDEAS	To create an awareness of an alternative viewpoint - the scientific one - to: a) modify b) extend or c) replace with a more scientific view.	
(i) Clarification and exchange	Recognise alternative ideas and critically examine own.	Small group discussion and reporting back.
(ii) Exposure to conflict situations	Test validity of existing ideas.	Teacher demonstration, performing personal experiments, worksheets.
(iii) Construction of new ideas	Modify, extend or replace existing ideas.	Discussion, reading, teacher input.
(iv) Evaluation	Test validity of newly constructed ideas.	Practical work, project work, experimentation, teacher demonstration.
IV APPLICATION OF IDEAS	Reinforcement of constructed ideas in familiar and novel situations.	Personal writing, practical activity, problem solving, project work.
V REVIEW	Awareness of change of ideas and familiarisation with learning process to allow the pupils to reflect upon the extent to which their ideas have changed.	Personal writing, group discussion, personal diaries, reviewing work posters etc.

Figure 1: Phases in the teaching schemes

It is recognised that children may keep their everyday ideas and their school science ideas as separate and distinct (Solomon 1983). This means that the science learnt in school may not necessarily affect children's practical knowledge in the long term.

We would hope to enable children to form links between their everyday ideas and their school science ideas. This process may be initiated by:

a) enabling the pupils to recognise their own everyday ideas that relate to the situation being studied

b) encouraging the pupils to verbalise their everyday ideas

c) helping to make the teacher become aware of the range of pupil ideas.

By stating their ideas either in writing or speech, pupils become more aware of what they think. This may stimulate a questioning of these ideas.

This process needs an accepting environment to work effectively; an environment in which a range of views are respected and valued by the teacher and pupils alike. In order to promote such an environment we have found that small group work is important. Pupils can talk and listen to each others' ideas without feeling that they are being checked.

In general, we recommend self selected groups and suggest that focus is given to discussion by asking pupils to record, in writing, the main outcomes of their discussion. We have had particular success asking pupils to prepare a poster to illustrate their ideas.

Other elicitation strategies may include:

- card sorting into 'true' and 'false' piles
- concept mapping
- discussion of responses given by other children
- written response to an open-ended question.

However, two points should be borne in mind:

a) pupils are less likely to respond with their everyday ideas if they expect the teacher to reject their answer for not conforming to scientific norms.

b) the social interaction of small group discussion may stimulate an evaluation of their everyday ideas if they are seen to be in conflict with those of their peers. We would therefore recommend that small group work be used in the elicitation phase.

Restructuring

Children's ideas may be resistant to change. They may be unwilling to change the way they see things simply because of one or two experiences in a science laboratory.

The exchange of ideas in the elicitation phase may provoke children to reconsider their thinking. Each discussion group usually reports back to the whole class so that pupils are made aware of the range of ideas that exist. This process is more effective if each discussion group produces a permanent record of its thinking such as a poster. This also acts as a stimulus and target during the discussion stage, and if posters can be left on display further informal discussion often ensues. The posters are also used as a permanent record of previously held ideas when the review stage is implemented. Some teachers may be concerned to put posters on display which contain ideas which appear 'incorrect'. A heading over the display such as 'Our Ideas On...' or 'Ideas of 4G About...' can get round this.

Teachers are now in a position to provide learning experiences which interact with the pupils' prior knowledge. In some cases, these experiences may extend the pupils' knowledge of the phenomenon where their ideas are seen to have limited scope (for example, pupils may think that all heavy objects sink), or they may help children to draw on several related ideas (for example, ideas about energy, states of matter and chemical reactions are all involved in lessons on plant nutrition). Alternatively the teacher may design activities to help children to change their ideas by providing experiences that challenge predictions, (such as dissolved solids 'disappear'), or to refine their ideas so that they are able to differentiate different notions (for example, heat and temperature or mass and weight).

By the use of various strategies, such as group discussions, modelling, games, simulations and informal writing or drawing we would encourage pupils to think about these experiences. In addition to providing opportunities for the use of their imagination we would aim to help children to become aware of the distinction between observation and theory, the criteria by which theories may be accepted and some of the currently accepted theories that explain certain phenomena.

Opportunities are then provided for reflection through practical activities, discussion or writing to enable the pupils to evaluate their own newly constructed ideas.

Application

If newly constructed ideas are to be accepted by the learner, these ideas have to fulfil certain criteria, such as: are these ideas useful, understandable and are they powerful enough to be applicable to a wide range of situations? People need time to become comfortable with new ideas and to use them.

Opportunities to apply new ideas in a range of contexts have been explored by the project. In addition to conventional written responses to questions we have tried the following strategies:

- problem solving e.g. building a model of an energy efficient house
- explaining novel phenomena
- exploring ideas through drama and role play
- imaginative writing

At the end of a unit of work a teacher was reflecting on what individual pupils had taken away from his lessons:

> "... if you could make them talk more - they would get the idea just as - clearly as I hope I've got it ..... Erm - whereas for me, as a teacher - you see - I shall teach this lesson three times - in one week - and then when I add up the number of years that I've been trying that I've got plenty of practice - but they haven't. The only practice they get is when we give them a test and we ask them to answer some questions."

Review

We have found that pupils are excited by an awareness of a change in their ideas and that they are able to articulate these changes. By reviewing the learning process throughout a scheme they are able to compare their initial ideas with those currently held. This does increase their motivation to learn and their involvement with the subject.

A range of strategies has been successfully employed to encourage this 'learning to learn'. Pupils have kept lesson diaries in which to record their personal reactions and thoughts on the lessons. Posters produced at the elicitation stage have been reviewed and later amended by the class. We have taken photographs during lessons and shown these to the class at the end of a unit as a basis for review. We have also used more conventional methods of review, such as giving a short test to compare ideas used with those they used when the same items were given as a 'pre'-test.

3 Demands on the pupil

3.1 Small group discussion

A free exchange of ideas and an acceptance of alternative view points may seem an ambitious goal. Yet with careful preparation, we have found that it is possible to hold a discussion in the laboratory.

There are various reasons for using discussion in science lessons:

- to elicit pupils' ideas
- to help children to clarify and refine their ideas by articulating them to others
- to make pupils aware of others' ideas and that a given phenomenon may be explained in a number of alternative ways
- to give pupils the opportunity to modify and restructure their ideas through social interaction.

Clearly, these various objectives are given different emphases during the stages in the teaching sequence. For example, at the beginning of a topic, discussion is obviously for elicitation and clarification of ideas; if designing an experiment or solving a problem then the relevant aims are an awareness of and the evaluation of alternative views possibly leading to a restructuring of one's own ideas.

Our experiences in science classes have indicated that there are several strategies that may improve the quality of discussions. The composition of the group is probably best left to the group themselves but we find that the size should not be allowed to go beyond five. Three, four or five participants provides a range of views but still allows active participation. Time limits should be set and a product helps to focus attention on the task. Generally we have found that producing a poster is useful as it focuses attention. Views expressed on a poster have higher status than spoken statements. Usually these views have undergone a vigorous screening process by the group, allowing only consensus views to

be recorded. The poster can then be used to inform the rest of the class and the teacher of the outcome of the discussion. It may also be reviewed in later lessons. However, the production of the poster should not detract from the quality of discussion and so it may be beneficial to provide paper and pens only towards the end of the discussion period.

We see discussion as a useful exercise only if it involves active participation where everyone's views are valued and everyone feels able to contribute. To be successful, the group must have a well defined task, be motivated into staying on task and reaching an endpoint. It is often helpful to move furniture into a circle to facilitate group interaction. Pupils should have defined roles, decided by the group (who takes notes, who produces the poster, who reports back to the class). Finally, it should be emphasised that although individual ideas are expressed, only consensus views should be put on a poster and recorded.

3.2 Reporting back

Following discussion in groups it may be necessary to arrange a reporting back session in order to familiarise pupils with each others' ideas. In addition to familiarisation with a range of views, we have found that this activity helps pupils to understand the status of their own ideas as only being part of a range of alternatives. This provides opportunities to help them to appreciate the status of theories in science. The experience of presenting ideas to a larger group is also a useful learning experience in itself. Not only does it develop children's confidence but it encourages them to review and refine their thoughts.

We have found that pupils who find reporting back intimidating, gain confidence when they can refer to a poster, or some other visual stimulus. The following discussion illustrates this point:

P1 It's hard when you have to go up there and just speak your mind. It's a lot better if you've got something you can actually show people.

P2 Yeah, 'cos you can focus on that as well.

P3 Yes, you can talk your way through it better, you know, you've got a better idea what you're doing.

P1 Yeah, 'cos with this you've sort of got all your ideas sorted out when you have to stand up. Without it in front of you you get in a muddle.

To increase the involvement of the class, we have found it is very important to rearrange the seating into a semi-circle. Each group nominates a reporter to recount their discussion to the rest of the class and it is helpful if this person is allowed some rehearsal time. The group's poster focuses attention away from the speaker, who may find it a useful prompt. A fellow group member acting as a 'poster holder' can be a helpful encouragement. Though, initially, some pupils can be embarrassed by reporting to other class members, this changes with experience.

During feedback sessions of this sort we have found that it also helps participation if the teacher sits in the circle with the pupils.

Interrogation by friends or the teacher often inhibits free discussion in the class and a negotiated set of report back rules may be necessary (such as no questions before the talk ends, questions should seek clarification not imply criticism). Similarly, speaking from a raised dias, or from behind a demonstration bench alienates the speaker and inhibits class discussion.

3.3 Writing

Writing in science lessons is usually done by pupils in order to make a permanent record of things that they need to know. Writing may also be used in science lessons as a way to help pupils think through ideas. When the act of writing is no longer seen as 'hard work' or even 'punishment' then pupils begin to enjoy the opportunity to express their own ideas. The CLIS teaching materials have used writing for a number of different purposes:

- to record group ideas on a poster. These views are concisely expressed in everyday language, with a view to recording for future reference, and for dissemination to the teacher and the class.

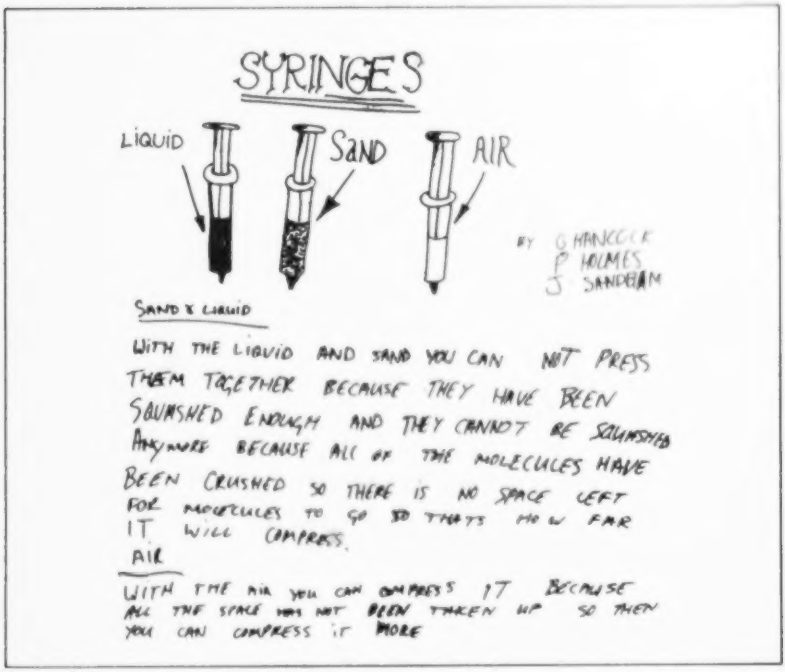

SYRINGES
LIQUID
SAND
AIR
BY G HANCOCK
P HOLMES
J SANDERSON
SAND & LIQUID
WITH THE LIQUID AND SAND YOU CAN NOT PRESS THEEM TOGETHER BECAUSE THEY HAVE BEEN SQUASHED ENOUGH AND THEY CANNOT BE SQUASHED ANYMORE BECAUSE ALL OF THE MOLECULES HAVE BEEN CRUSHED SO THERE IS NO SPACE LEFT FOR MOLECULES TO GO SO THATS HOW FAR IT WILL COMPRESS.
AIR
WITH THE AIR YOU CAN COMPRESS IT BECAUSE ALL THE SPACE WAS NOT BEEN TAKEN UP SO THEN YOU CAN COMPRESS IT MORE

Figure 2: A poster drawn by 13 year old pupils to explain their own ideas on the differences in compressibility between solids, liquids and gases.

- to record their own personal views in an exercise book. This piece of work helps to elicit and clarify an individual's ideas and is written in their own language. It forms a record of their current thinking and is a very useful source of information for the teacher. Some technical words may be used, but the teacher should be aware that the pupil's meaning may not be that used by the teacher.

Energy is used up when you put afor example iron oxide with magnesium and heat it. This is called a reaction

Energy is used up when you put for example iron oxide with magnesium and heat it. This is called a reaction.

When particles move about in a ballon, when it is getting blown up. Energy is been used up.

When particles move about in a ballon, when it is getting blown up. Energy is been used up.

heat is made when energy is burnt

heat is made when energy is burnt.

Figure 3: 13 year old pupils writing about energy

- to direct pupils' thinking towards a specific end point. In the following example pupils were set the task of planning an experiment to test their ideas about how plants get their food. In this case, not only does preparing a written plan help to focus the pupils' thinking on what they are going to do, but it also provides information for the teacher as to the equipment required for the next lesson.

Form: 3rd How Do Plants Get Their Food? Name: RUTH HAYNES

1/ What idea are you testing out in your experiment?

We want to see if it is necessary for plants to have light to make their food.

2/ How are you going to do your experiment?

We will put a plant seed into each of the 2 test tubes. It will be placed on a bed of soggy cotton wool. One of the tubes will be covered up and stood away with the other for a week and the other will be left open in the air. After a week we will be able to see if light is essential to a plant.

3/ Make a list of the equipment you need:

2 Test Tubes

2 pieces of cotton wool about 3cm in depth.

Some plant seed that cannot have energy stored up in them already.

(Use back of sheet if needed)

4/ Who else is in your group?

Elaine

Sarah

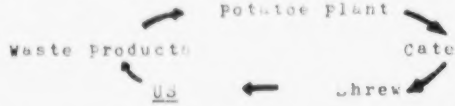
Figure 4: An outline of an investigation produced by three 13 year old pupils

- to provide accounts of work undertaken. This work is exploratory in nature and acts as an end point for an individual or group study. The language is the pupils' own, but they can be encouraged to use words in a concise manner. The illustration is an extract from a typed report produced by three pupils in response to the task "Design a life support system that provides food and oxygen for three astronauts living in space".

Food Cycle.

Starting off

Our original idea involved a fairly lenthy cycle, hopefuly providing nearly all of the foods man needs to survive. Time was the main factor because if one part of the cycle could not keep up with the demand the cycle would grind to a holt. Therefore we decided to pick fairly fast reproducing participents. However at first (as you will see) we did not take this into consideration. His was our food cycle.



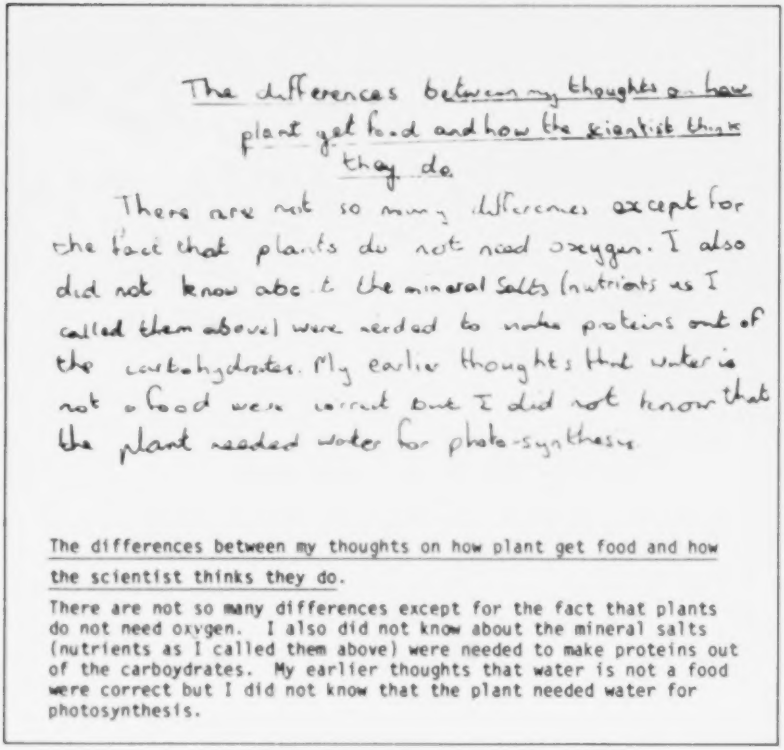
We orifinaly chose the potatoe plant because it provided a lot of the foods we required. We had though that it would last out the three weeks, but as you will find out in "food chains" it will not meet up with demand. Therefore with just one weak link (there are more in this example) the cycle will stop.

Our Second Idea

Then Collin came up with another idea that of

Figure 5: An extract from a seven page document typed by a group of 13 year old pupils

- to review a change in their ideas. Many children have found this an intriguing exercise; it also provides further motivation for learning.



The differences between my thoughts on how plant get food and how the scientist thinks they do.

There are not so many differences except for the fact that plants do not need oxygen. I also did not know about the mineral salts (nutrients as I called them above) were needed to make proteins out of the carbohydrates. My earlier thoughts that water is not a food were correct but I did not know that the plant needed water for photo-synthesis.

Figure 6: A review of the change in one pupil's ideas on plant nutrition

- to keep a diary of their feelings and ideas. This may be kept private, or can be commented on by the teacher. Diaries have provided teachers with insights into their pupils' thinking and the pupils have found the writing of diary entries to be interesting and motivating.

12.December.

Todays lesson we discussted mainly on the Gases and to find out as a class a solution to weather or what Gases have inside them. Some people came up with the idea of particals and that lead on to particals in liquides and solids. MrScott had turned all of the clocks around I supose so that we could either look at the posters or look over Nunroyd park instead of himself. HA HA HA. In my mind we still didn't say weather there are or arent and particals in the three(subjects) - liquids, Solids Gases. My Mind is still pondering on it know as I write my diary. Sir Somebody must know the answers to the Question because there has to be some kind of answer to every Question BUT it is finding the wright one I find the problem. On the hole it was a very Interesting lesson. Its not very often in class discution when somebody says something and nobody laughs at what that person has said.

Figure 7: Heather's diary

It is unhelpful to confine all of these written activities to exercise books:

- small notebooks may be most suitable for diary entries
- scraps of paper appropriate for jotting down ideas in a brain-storming session
- several sheets of rough paper to allow draft copies to be refined before producing a 'good copy' of a report.

A word processor would be extremely useful for this last purpose.

Many pupils do not regard all of these activities as 'work'. This type of writing provides valuable feedback for the teacher, but in return the pupils often demand a grade or mark from the teacher. The implications of this are discussed in the next section.

3.4 Testing ideas

Giving children the opportunity to test out their own ideas experimentally can be an important way to help their ideas change and develop. In our experience very few pupils had been given opportunities to undertake their own investigations before and so needed some support from the teacher to help them structure their thinking.

When pupils make their ideas explicit it can be a useful development to let them test these ideas for themselves. Ideas such as 'air is weightless' or 'heat rises it doesn't go down' or 'plants get food from the soil' are all open to tests. Even though it is time consuming, there are many reasons for giving pupils opportunities to test out their ideas experimentally:

- We have found that it is very motivating for pupils to test their own ideas. There is an extra commitment to the activities which results in youngsters coming to the labs at lunchtimes and after school to check their investigation.

- Testing their own ideas requires pupils to clarify their thinking in order to put their ideas to the test. What criteria, for example, should be used to tell if their idea is supported or not? The need to clarify their thinking is clear in the following example where youngsters were investigating plants' need for water:

Pupil 1 Could we pot a little plant or summat with dry soil and no water to prove that it does need water to survive on.

Pupil 3 And water is energy so they have to be in soil to ...

Teacher Are you sure about that? Water is energy.

P3 Well water is part of the energy for the soil.

Pupil 2 It can't survive without water.

Pupil 4 Let's put it in sand.

P2 Even though it will have light....

T Just hang on a minute. Are you deciding that it needs water or are you deciding that the water gives it energy?

P2 Well it needs water.

P3 ... stuff out of t'soil.

P4 Let's put sand in and it won't be able to live.

P1 No, you have to put dry soil in.

There is apparently some confusion as to the function of the water here. However the extract does show pupils' concern to set up a fair test (they reject the comparison of one plant in the soil and one in sand).

P4 That's it, that's what I meant. Right, so we're leaving it for a week without water, but it's got to have everything else it needs. It's got to be in the light, hasn't it, that sort of proves ... Just stick it on a window sill, without water.

P2 Make sure it has light.

P3 We can just label it.

P4 Yes, no water for a week. Please do not water this plant.

P2 And then somebody will go and water it.

P1 No, if we have it in t'biology lab., and it's kept in that room where we kept it before, it should be alright.

P4 If we have it up there ....

P1 We'll just have to take that chance.

P2 And like we can come and check on it and see how much it's shrivelling up and dying, can't we?

As any researcher knows the most difficult part of an investigation can be clarifying the question and putting it in a testable form. In more formal language the issue is deciding what is the dependent variable (and what is an appropriate indicator of it), what is the variable to be manipulated, and what variables need to be controlled.

Can you trust the results you get? This depends, among other things, on whether the effects of other possible factors on the dependent variable can be ruled out. In other words it depends on whether the test is a 'fair' one, one in which other possibly influential variables have been controlled. In our experience pupils may need reminding to think about this, but once reminded they appreciate the need for controlled tests. (What they consider to be the possibly influential variables, however, may not coincide with those a science teacher would suggest.)

In order to give the necessary support to pupils to design their own investigations we suggest it can help if:

- pupils work in groups

- each group prepares a written outline detailing:
  - the idea to be tested
  - the way the test is to be carried out
  - how to ensure the test is fair
  - the apparatus needed

The teacher can review the progress in the thinking of each group through these written records. The written plans can also be presented to the class for review prior to being tried out. Pupils can learn by critically reviewing each others' plans whether an experiment is a 'good one' or not in terms of whether it will answer the question set.

In this way, pupils can appreciate that doing an experiment involves a great deal more than following a set of instructions. One or two extended experiences of undertaking a genuine investigation themselves gives an appreciation of design of experiments which it is hard to gain in any other way.

Clearly designing and carrying out their own investigations demands a great deal of the pupils and teacher, but is nonetheless valuable in providing children with an insight into investigative activities and proves to be very stimulating for the pupils. It also acts as a powerful challenge to the pupils' ideas even if experimental evidence does not by itself promote change in pupils' thinking.

3.5 Providing experiences and time to think about them

By providing time for pupils to discuss their experiences with each other after performing each activity they are given the opportunity to restructure their ideas.

We have found that this process of restructuring can be rather lengthy, and it does not necessarily end when children leave the laboratory. Teachers have reported feeling frustrated at the end of a lesson by the confusion of ideas proposed by children, only to find that by the next lesson these ideas had been refined and now conformed with the teacher's original expectations.

3.6 Reviewing ideas

By comparing their initial ideas with those currently held, pupils are given the opportunity to become aware of their own learning. We have found that this provides motivation for further learning and encourages children to become more involved with their lessons.

There are a number of strategies which have been used to review ideas by individuals, groups, or the class as a whole:

- individual review of changes in knowledge provided as a written homework exercise - see 3.3

- group production of a poster at the end of a unit to compare with other posters produced in the course

- class review of posters produced earlier in the course. Either verbal or written amendments may be made to the original posters.

3.7 Choice

At several points in the teaching schemes pupils are given a free choice of activities to pursue, ideas to test, or subjects to discuss. Pupils are responsible for their own learning and are most likely to learn what they are interested in. By being given a choice, we find individuals are more motivated to learn. Certainly feedback from pupils indicated that they valued having a say in the activities they did.

4 Demands on the teacher

This section suggests some ways of managing learning situations and points out some possible pitfalls. There are also some comments made in Sections 4.4 and 4.6 about how we view science and the question of assessment.

4.1 Discussion

Some teachers have expressed the fear that learning will not occur unless the teacher is present in group discussions. We have found the opposite can be the case, and when teachers interfere with discussion groups the participants may become less spontaneous and less likely to contribute their own ideas. Teachers should see their role as managers but not controllers of the situation.

This role will include:

- ensuring all pupils understand the task
- negotiating rules for operation of the groups
- setting a time limit
- supervising furniture 'removals'
- providing large sheets of paper and a marker pen for poster production AFTER the discussion has begun
- pointing out that the standard of presentation is only of secondary importance
- clearing a space for poster display
- asking each group to provide a spokesperson

and most importantly:

- providing a non-threatening environment by encouraging ideas rather than judging ideas.
- enabling pupils to evaluate each others' ideas.

We have found that group discussion is most successful when the groups have been allowed to determine their own composition. On occasions some teachers have found it necessary to exercise control over which pupils may work together, but we feel that this adversely affects the working atmosphere.

4.2 Reporting back

As with group discussion, the teacher needs to be aware of adopting a non-judgemental role. If the ideas of the pupils are to be openly discussed by the class then they must be perceived as being of equal status in the eyes of the teacher, irrespective of whether they are considered 'right' or 'wrong'. In sessions where the teacher interrogated each group in turn, little class discussion followed as groups 'picked up' teacher responses to each statement and therefore saw little value in discussing ideas already judged by the teacher.

One teacher commented:

> "I felt I was almost in the position of an interrogator at times, trying to get them to say a little bit more and I don't know whether that's a good idea because I was putting kids who came out to talk on the spot a bit, and some of them were reluctant enough to come out anyway."

whilst another said:

> "I was surprised there was no difficulty in groups finding spokespersons. There was one person from each group ready to explain the ideas of the group as depicted on the poster ... They were quite keen to share ideas, however limited."

Certainly some pupils find the task of reporting back very difficult and teacher encouragement is needed. As mentioned before, the situation is less threatening if:

- rules for reporting back are negotiated
- the spokesperson is allowed time to rehearse

- posters can be referred to

- a friend can hold the poster

- the seating is arranged informally and close enough for all pupils to see and hear

- the session is not focussed around a blackboard or demonstration bench.

One function of the session is to make all pupils aware of other groups' ideas. It is more effective for the teacher to summarise the main points on an overhead transparency or blackboard, as each point is discussed. Again, to be supportive, all ideas should be included in the summary, even if they replicate previous groups' views. After the session the class can suggest overlaps so that the list of ideas is condensed. Summarising the class's ideas is not an easy task and requires quick thinking.

A researcher watching a teacher handling a class discussion and report back session said after the lesson:

> "I actually think that what you had to do in that lesson is probably one of the hardest things from the whole scheme. I think that the reporting back and pulling everything together from the experiments are both incredibly hard. I mean, I think you were very cool. I mean, I was totally panicked (laughs). I couldn't think straight at all."

The question of control and direction of events is a difficult one. How does one achieve a compromise between direction or guidance, and domination?

> "Well - to be honest, in the past - within that double lesson I'd have had all things sorted - I'd have had my little diagrams up on the board - solids, liquids, gases - erm - I mean a normal lesson is - I introduce something, we discuss it maybe round the front, and then there's a nice practical work in the middle and I talk around, and we you know enjoy doing a bit of practical work - and then come back to the front - finish it off - and you know that's

it. That's very much the pattern. So the last lesson seemed to be distorted from that point of view as well. But - I mean - this section doesn't lend itself to that kind of approach at all - it would seem."

In his diary, this teacher added:

"The lesson left me feeling strangely frustrated. The class had responded to the group discussion extremely well - contributions came from all corners. From my point of view the discussion went on far too long, although valid points were being made by pupils to the end. The class had aired their own ideas and then put their ideas up for debate. I suppose that normally I would direct events more by pushing my own ideas. By the end of the lesson, many ideas had been aired and one or two specific points established. In retrospect, a reasonable start."

Points to watch for:

a) Initially, teachers feel panicked by the range of ideas. Be patient - pupils often sort them out with some guidance from the teacher.

b) Beware of wanting to 'force the pace' and get closure too soon. Questions may be left open to provide a useful focus at the start of the next lesson.

4.3 Testing ideas

Teachers initally saw this activity as being fraught with dangers:

"My own feelings were of unease to begin with - 'fear of the unknown' I suppose - not being able to have everything 'cut and dried' before the lesson!!! I relaxed when I realised the atmosphere was relaxed and buzzing!"

If this activity is novel to pupils as well as teachers then we should also bear in mind the enormity of the task we have asked them to undertake - understanding on both sides may be needed.

The teacher has four major contributions to make:

- provide equipment
- ensure the activity is relevant to the problem to be solved
- ensure the design of the activity is realistic and practical, and that it will produce some data
- ensure the conclusion reached is in accord with the data obtained.

The first two points can partly be solved by setting a homework task to describe the investigation and list the necessary equipment. The last point is made easier by asking each group to record their investigation on a poster (which can later be used for reporting back).

It is unreasonable to expect children to be able to plan elegant investigations before they have had considerable practice. By providing opportunities to try out their own investigations the pupils quickly become aware of mistakes in their thinking and the difficulties in producing meaningful experiments.

4.4 The status of scientific knowledge

In this approach to science teaching we are aware that children need time to think through and construct ideas for themselves. For this reason we avoid 'short circuiting' this process by providing 'right answers' too quickly. Some children felt uneasy over this, but we feel that they should be given opportunities to develop confidence in their own ideas. Their lack of confidence has been revealed by:

- pupils demanding a mark at the end of an account of their own ideas, in spite of copious written comments made by the teacher
- pupils demanding the right answer of the teacher in a class discussion of their ideas
- explaining unexpected results in practical work in terms of 'we must have done something wrong' or 'it hasn't worked'

Pupils have certain expectations before they come to lessons and possibly due to earlier encounters with science they see science as a rigid body of knowledge which needs to be learned if they are to become 'good at science'. Other subject areas have encountered the same problem in the past, but due to a change in approach and curriculum, say for example in history, pupils' perceptions of the subject have changed. This has resulted in pupils changing their expectations and consequently their behaviour in these subjects.

Our approach to this has been to acquaint children with scientific ideas, and to allow them to explore these ideas alongside their own. By developing an understanding of the ways that scientific theories are developed and validated, pupils begin to recognise scientific knowledge as a useful way of explaining and predicting their experiences. This knowledge is recognised as being constantly reviewed and refined. We have introduced children to scientific ideas both formally (with the use of prepared handouts) and informally (by suggesting ideas in the course of a discussion).

4.5 Marking

Throughout the CLIS teaching scheme there is less written work set than in traditional teaching schemes, and it serves different purposes. Consequently there may be less work to mark, but the marking that is done also serves different purposes.

When responding to written work the teacher must be sure of what criteria are being used to assess it and that these criteria are made explicit to the pupils.

Outlined below are some strategies for marking that we have employed:

Task set	Teacher response to pupils' work	Feedback to teacher
Write down your ideas.	Encourage clear styles of writing. Respond positively to ideas. Encourage deeper thinking.	A clear awareness of pupils' initial ideas.
Record how you performed your experiment on a poster.	Encourage: - accuracy of account. - correct use of terms. - conclusions consistent with results. Results presented in appropriate manner.	Quality of experimental design, other scientific skills and communication skills.
Write an account of how the scientific theory varies with your own initial ideas.	Encourage a detailed response. Correct mistaken spellings of technical words or misunderstandings of scientific theory. Encourage clarity of response.	Awareness of conceptual change.

In these examples, a mark out of ten was thought to be inappropriate and the reasons for this were clearly explained to the class. Individual comments from the teacher in some cases developed into written dialogues between the teacher and the pupil allowing further awareness and respect for each other's ideas. Opportunities for this depth of relationship are rare in the hurly-burly of school science laboratories.

Some teachers were concerned that by asking pupils to express views that the teacher considered unscientific, these views might be reinforced in the pupils' minds. This feeling of doubt was increased if work merited an encouraging remark by the teacher or if it was 'ticked'. Providing that teachers make their marking criteria explicit, the pupils accept that they are expressing views and that they are not being judged for 'correctness'. In this type of work it may be useful for teachers to write their comments in blue or black ink if they wish to foster an atmosphere of co-operative communication.

4.6 Assessment

School assessment takes many forms and serves many purposes:

- Pupils' awareness of their learning. Built into the teaching schemes are formalised opportunities for review, giving pupils a deeper understanding of their learning than can be obtained from traditional end-of-topic pencil and paper tests.

- Teacher awareness of pupil learning. Through written work of an individual nature, or through group posters the teacher becomes much more aware of the pupils' thinking and progress. When topics are open-ended far more information on pupils' understanding can be obtained than from closed objective test questions.

- Parent awareness of pupil learning. By learning becoming a more pupil centred activity teachers are able to recognise individual qualities within their pupils. They are then able to respond more positively at parents' evenings or when writing formal reports.

- Formal internal or external assessment (GCE, CSE, GCSE). By recognising the mechanisms by which pupils learn and adopting appropriate strategies children's understanding of concepts improves and hence pupils perform well in tests that assess understanding.

- Profiling. Formative profiles involve negotiating a consensus statement of performance between pupil and profiler. The child-centred approach makes pupils, as well as their teachers, much more aware of their own strengths and weaknesses. Profiling may be the most appropriate form of assessment for outside organisations when using this approach.

5 Demands on resources

5.1 Time

A major concern for teachers has been the amount of time needed for the implementation of the schemes. The schemes are expensive in terms of time. However, a number of points have been raised which may be relevant to this problem:

> "If we can get the basic concepts right to start with then we don't have to teach them the same thing again later on."

> "What surprised me was those APU results. Only 30% of the children really understood particles after they have been through five years of secondary school."

> "You're always under pressure to get through the syllabus. Now they say they have reduced the content for GCSE maybe we can afford the luxury of some proper teaching."

When one looks at complete transcripts of a number of lessons this one-sided state of affairs becomes very apparent. Comment from a teacher on seeing lesson transcripts for the first time:

> "- it also makes you realise how much time the teacher spends talking. You know, as opposed to youngsters actually doing something."

5.2 Materials

Along with the normal items of science expenditure, the CLIS teaching schemes require the use of several items of stationery including:

- large (A2) sheets of paper for posters, coloured if possible. Wallpaper can be bought cheaply from most DIY shops in an emergency.

- large tipped poster pens, magic markers etc. In an emergency the lost property box often contains an assortment of felt tips.

- blu-tack for fastening posters to walls if there is no noticeboard available. Alternatively, sellotape posters to glass, or use acetate sheets and an OHP with wipeable marker pens.

- plasticine for model making

- scissors and glue

5.3 Equipment

As there are more opportunities for group work in the schemes, there are fewer formal practical sessions and, therefore, demands on science apparatus are not so heavy. Where pupils design their own experiments, the demand is usually for basic apparatus, unless the teacher permits them to wander into the exotic field of vacuums, powerful microscopes and frictionless movement. However, there may be a heavier than usual demand for:

- photocopying

- OHP's

- reference books

5.4 Laboratory technicians

Giving pupils a free rein to test their own ideas or to undertake an open-ended project raises some organisational problems. Even training pupils to plan their investigations carefully and to hand in lists of equipment before the lesson cannot cover every eventuality that arises in the course of the investigation. If a laboratory technician can arrange to be on hand for ten minutes in that particular lesson then the pressure on the teacher is considerably eased. However, the presence of a technician is certainly not crucial to the success of the exercise.

Some lessons within the schemes do not require scientific apparatus, hence the overall need for technical assistance may be less than with more traditional science teaching.

5.5 Rooms

Discussion and reporting back can be inhibited by inflexible furniture arrangements that are found in older school laboratories. For several of the lessons within the scheme it may be beneficial to move into an ordinary classroom if this does not unsettle the pupils. This should not be considered as a novel situation. It is merely a method of facilitating the process of learning, by avoiding the distractions of the laboratory.

Postscript

From a teacher:

> "To my great shame, one pupil commented to the research worker at the end of lesson three that she had enjoyed the lesson because, 'It's not often that we are asked what we think in a science lesson'."

From a pupil:

> "I think being left alone to work out the problems was better for me than just being told what was true and what wasn't, because it gave me a chance to come out with my own theories and opinions - even if they were wrong it gave me the experience of actually doing something without having to use someone else's findings to help me. When we found out the right answers at the end, it was interesting to see how close our own theories came to them. The whole exercise gave us a better chance to think logically about problems."

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Further reading

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The Children's Learning in Science Project

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